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Simulation of CO_2 and sensible/latent heat fluxes exchange between land surface and atmosphere over cropland and grassland in semi-arid region, China

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Abstract: A comparison between simulated land surface fluxes and observed eddy covariance (EC) measurements was conducted to validate Integrated Biosphere Simulator (IBIS) at Tongyu field observation station (44°25′N, 122°52′E) in Jilin Province, China. Results showed that the IBIS model could reproduce net ecosystem CO_2 exchange (NEE), sensible and latent heat fluxes reasonably, as indicated by correlation coefficients exceeding the significant level of 0.05. It was also evident that the NEE and sensible heat fluxes were characterized by diurnal and seasonal variation both in the grassland and the cropland ecosystems, while the latent heat fluxes correlated with evapotranspiration, only took on the diurnal variation during the growing season. Moreover, both sensible heat fluxes and the latent heat fluxes were larger in the cropland ecosystem than that in the degraded grassland ecosystem. This different characteristic was possibly correlated with vegetation growing situation in the two kinds of ecosystems. A close agreement between observation and simulation on NEE, sensible heat fluxes and latent heat flux was obtained both in the degraded grassland and the cropland ecosystems. In addition, the annual NEE in the model was overestimated by 23.21% at the grassland and 27.43% at the cropland, sensible heat flux with corresponding 9.90% and 11.98%, respectively, and the annual latent heat flux was underestimated by 4.63% and 3.48%, respectively.

Keywords: Integrated biosphere simulator (IBIS); CO_2 flux; Sensible flux; Latent heat flux; Cropland ecosystem; Grassland ecosystem;

Introduction

The terrestrial biosphere is an integral part of both the global carbon and hydrological cycles. Every year about 14% of the carbon in the atmospheric is exchanged with the terrestrial biosphere, and about 20% of the water added to the atmosphere annually derives from evapotranspiration from the land (Wesfall and Stumm 1980; Friend 1997). Researches on carbon and hydrological cycles of the terrestrial ecosystem have been one of the main issues in the global change science. For the purpose of predicting the development trend of global change in the future and seeking the effective ways to regulate carbon and hydrological cycles of the earth ecosystem, it is necessary to have an acquaintance with each process and feedback mechanisms of these two cycles in the terrestrial ecosystem. Dynamic models coupled carbon and hydrological cycles have been developed primarily to fulfill this need, for example, BATS (Dickinson 1986), FOREST-BGC (Running 1988), BIOME-BGC (Running 1993), AVIM (Ji 1995), IBIS (Foley 1996), SIB2 (Sellers 1996), TEM (McGuire 1997; 2000) and so on.

At present, these models have been widely applied in research of carbon and water fluxes exchange between land surface and atmosphere. However, the verification and validation of models based on field observations in different temporal and spatial scales are greatly needed, and as a result, scientists and researchers should still pay enough attention to these aspects. Among various methods for measuring the field data, the eddy correlation method (EC), one of the micrometeorological methods, is a promising method lately developed. It provides a relatively direct means of measuring fluxes, without the need for assumptions regarding diffusivities and without making assumption about the nature of the surface cover (Verma1 990). Recently the eddy correlation method has gained predominance among micrometeorological methods because of its minimal theoretical assumptions and improved instrumentation (Shuttleworth 1993).

The long term field experiment on aridification and the ordered human activity in semi-arid area at Tongyu, northeast China, has been launched since 2002, which is also one of the reference sites of the Coordinated Enhanced Observing Period (CEOP). CEOP was originally envisioned as a major step towards bringing together the research activities in the GEWEX Hydrometeorology Panel (GHP) and is being developed and implemented within the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP). At the Tongyu observation station, the micrometeorology and energy flux data measured by EC were collected since

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the October 2002, which can be used in comparison with model outputs.

In this study, we apply a new version of the integrated biosphere simulator (or IBIS) of Foley (1996) and Delire (1999), which has improved representations of land surface physics, plant physiology, canopy phenology, plant functional types and carbon allocation (Kucharik 2000). For the purpose of evaluating the ability of IBIS to reproduce the main biophysical processes occurring at the land surface, we present model simulations of net exchange of CO_2, latent and sensible heat fluxes at Tongyu, and also make a comparison with the CEOP reference site observations.

Materials and methods

Study site

The Tongyu CAMP observation station (44°25′N, 122°52′E, 184 m elevation), located in Xinhua Town, Tongyu County of Jilin Province, is composed of a cropland and a degraded grassland. The cropland cultivates maize from May to early October every year, and during the other period, the land cover is bare soil surface. At the degraded grassland, the grass can only reach a maximum height of 10 cm during the growing seasons. The soil textural class in this site is sandy loam, containing 60% sand, 35% clay and the remaining 5% silt. The plant functional type is cool (C3) grass, and the seasonal evolution of the leaf area index is estimated by Zhao *et al.* (2002). It is characterized by the climate with evident mainland monsoon. The average temperature of 30-year is 5.5ºC and the annual precipitation is about 345.4 mm.

Turbulent flux observation system is composed of ultrasonic anemometers/thermometers (CSAT3, Campbell Scientific Ltd, USA) and CS7500 Li-Cor open path CO_2/H_2O analyzer.

As the cropland and the degraded grassland exist under the control of similar climatic conditions, we only present the main meteorological data of Tongyu grassland ecosystem in 2003 (Fig. 1). Among them, data from 21 April to 11 May are missing.

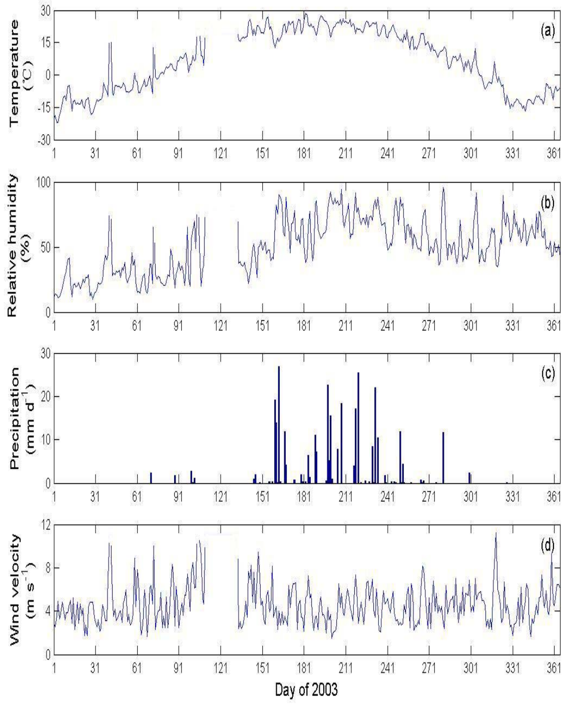

Fig. 1 Meteorological conditions of grassland ecosystem in Tongyu Observation Station in 2003: (a) air temperature, (b) relative humidity, (c) precipitation and (d) wind velocity, in which (a), (b) and (d) are daily mean values while (c) is daily amount.

Method

IBIS (version 2.6) is a fairly comprehensive model of terrestrial biosphere processes and includes four modules of (1) land surface processes, (2) vegetation phenology, (3) terrestrial carbon cycling, and (4) vegetation dynamics (Foley 1996).

The land surface module uses a two-layer vegetation, six-layer soil scheme to simulate the surface energy, water, carbon, and momentum balance of the soil-vegetation-atmosphere system with a relatively short time-step (Delire 1999). This module borrows much of its basic structure from the LSX land surface package (Thompson and Pollard 1995a; 1995b). Physiologically based on formations of canopy photosynthesis (Farquhar 1980; Farquhar and Sharkey 1982), stomatal conductance (Collatz 1991; 1992) and respiration (Amthor 1984) are used to simulate canopy gas exchange processes. The above processes are organized in a hierarchical framework and operate at time steps ranging from 60 min to 1 year. And this approach allows an explicit coupling among ecological, biophysical, and physiological processes occurring at different time scales. More details on the IBIS model are described and given by Foley (1996) and Kucharik (2000).

Results and analysis

We present simulations of surface fluxes for the whole 2003 output by IBIS and make a comparison between model results and the observed data at the Tongyu site, so as to evaluate the performance of the model.

Net Ecosystem CO_2 Exchange (NEE)

The NEE included in the eddy correlation measurements were used to test the simulation of the physiological processes linked to photosynthesis and respiration in the model. Because the photosynthetic process is mainly related to the variation of the stomatal conductance, the NEE can provide an independent way to assess the transpiration simulated by the model (Delire and Foley 1999). Simulated versus observed NEE of the grassland and cropland are presented in Fig. 2. Results indicate that the two kinds of ecosystems serve as weak carbon sinks, which took on minus NEE for almost a whole year. Moreover, simulated NEE in growing seasons (mainly from April to September) are larger than those in the other period. On the basis of comparison analysis between simulated and observed NEE, a fair agreement is shown in the two kinds of ecosystems, and the correlation coefficients (R^2) in grassland and cropland is 0.41 and 0.49, respectively.

Shown in Fig. 3 is the monthly mean NEE of the grassland and the cropland ecosystems at Tongyu site in 2003. On average, the values of simulated NEE are higher than those of observed and they both reach the maximum in August. Meanwhile, some

differences between simulated and observed NEE are observed from May to August, especially in the cropland ecosystem. In general, the simulated NEE of the whole 2003 year accumulates up to -443.33gC·m^{-2}·a^{-1} at the grassland and -581.32gC·m^{-2}·a^{-1} at the cropland, overestimated by 23.21% and 27.43%, respectively.

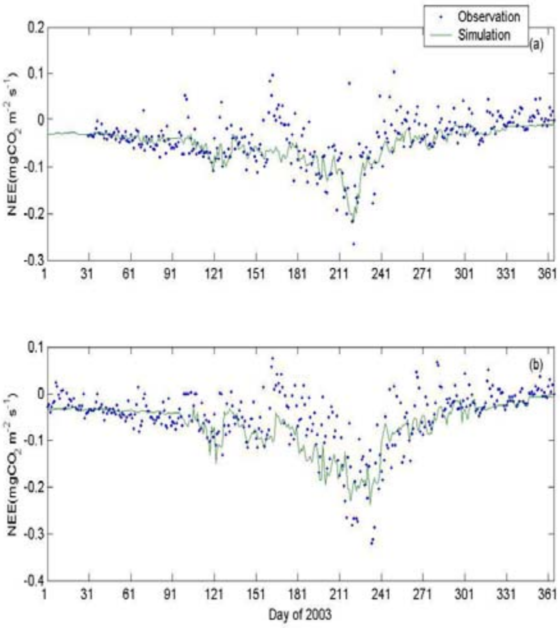

Fig. 2 Daily average of simulated and observed CO2 flux (NEE) at Tongyu Reference Site in 2003: (a) denotes the grassland ecosystem and (b) the cropland ecosystem. The observed flux data of grassland from 1 to 29 January are missing.

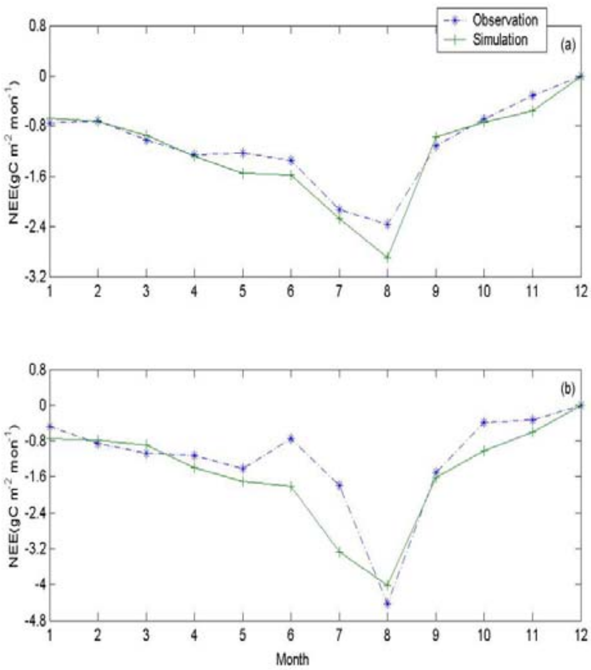

Fig. 3 Monthly variation of simulated and observed CO2 flux at Tongyu Reference Site in 2003: (a) grassland ecosystem and (b) cropland ecosystem.

Sensible Heat Flux

The time evolution of the sensible heat flux simulated and observed for the whole 2003 is shown in Fig. 4. The sensible heat is generally well simulated by IBIS. The close agreement between observation and simulation on NEE was obtained both at the degraded grassland and the cropland, with R^2 0.76 and 0.72. However, their maximum sensible heat fluxes are all underestimated, especially in the cropland ecosystem. Due to the differences in characteristics of underlying surfaces, both the simulated and observed sensible heat fluxes are higher at cropland than those at grassland during the growing seasons.

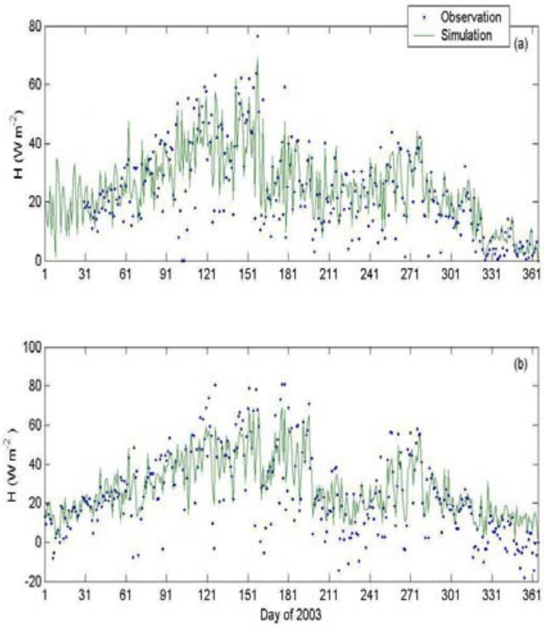

Fig. 4 Daily average of simulated and observed sensible heat flux (H) (Others are same as Fig. 2)

As shown in Fig. 5, the similar trend in NEE was observed in monthly variations of simulated and observed sensible heat fluxes. At the degraded grassland the simulations of monthly mean sensible heat flux are mostly higher than observations (overestimated by 9.90% for the whole 2003); while at the cropland the simulations are basically in accordance with the observations during the growing seasons except from July to August and November to December. As a result, the accumulation of simulated sensible heat flux reached 10 234.05 W·m^{-2}, which is overestimated by 11.98% as compared with the observation (9 138.39 W·m$^{-2)}$. This is due to the inaccurate simulation for the growth process of maize in the cropland ecosystem.

Latent Heat Flux

The agreement between simulated and observed latent heat flux is quite reasonable although the maximum latent heat flux is often underestimated from July to August (Fig. 6). The squared correlation coefficients in the grassland and cropland ecosystems are 0.82 and 0.84, respectively. Meanwhile, the maximum of simulated latent heat flux in the cropland ecosystem is about

twice that in the degraded grassland ecosystem, which resulted from the partition between grassland and cropland in the IBIS model. The latent heat flux both in the grassland and cropland ecosystems only has diurnal variation during the growing season. While in the non-growing season underlying surfaces are covered with bare soil, thus the latent heat flux in the two ecosystems is usually less than 30 W·m^{-2}.

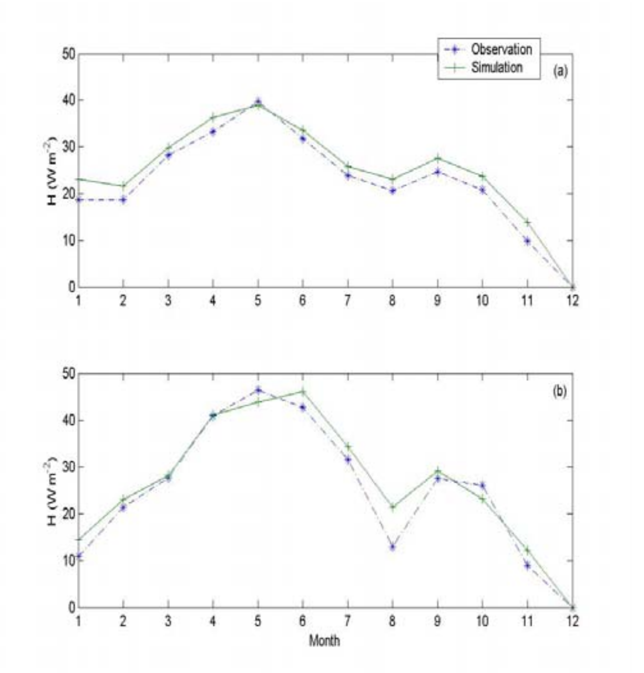

Fig. 5 Monthly variation of simulated and observed sensible heat flux in Tongyu Observation Station in 2003 (Others are same as Fig. 3)

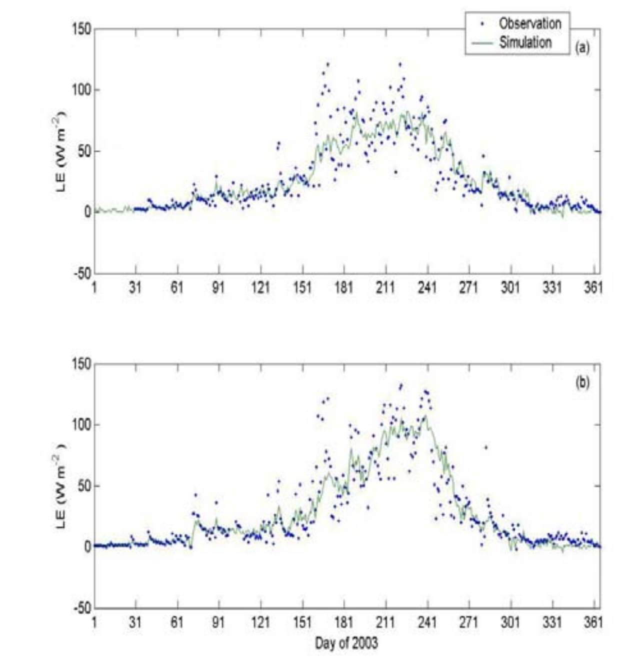

Fig. 6 Daily average of simulated and observed latent heat flux (LE) (Others are same as Fig. 2)

Fig. 7 presents the annual variations of simulated and observed latent heat flux at the grassland and cropland in 2003. From the comparison of the monthly mean latent heat flux, it can be found that the simulation is very close to the observation except in June and September. In general, the accumulations of simulated latent heat flux for the whole 2003 at the grassland and cropland was 9 325.62 W·m^{-2} and 10 161.41 W·m^{-2}, respectively, while the corresponding values of observation were 9 778.16 W·m^{-2} and 10 527.51 W·m^{-2}, underestimated by 4.63% and 3.48%, respectively.

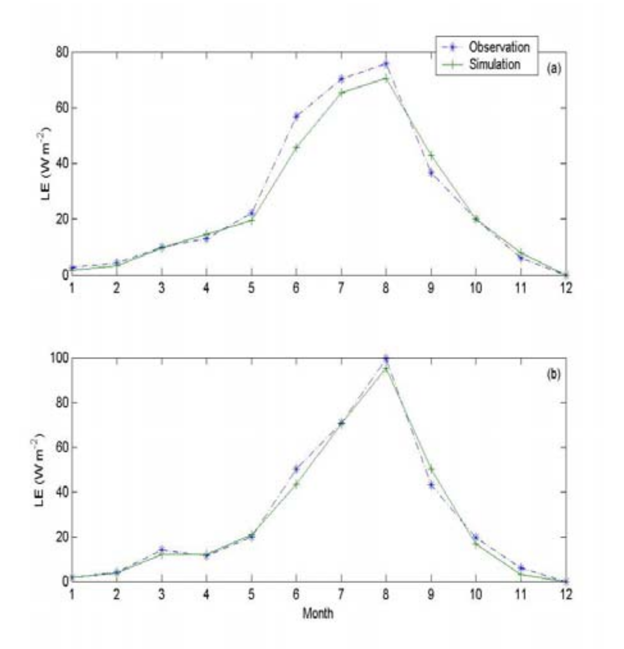

Fig. 7 Monthly variation of simulated and observed latent heat flux in Tongyu Observation Station in 2003 (Others are same as Fig. 3)

Concluding Remarks

In this paper, we made a comparison between the IBIS simulation and the eddy correlation measurements of NEE, sensible and latent heat fluxes for the whole 2003 at Tongyu site, a semi-arid region in northeast China. Our results show that the IBIS could reproduce NEE, sensible and latent heat fluxes reasonably, as indicated by correlation coefficients exceeding the significant level of 0.05. Generally speaking, the model overestimated the annual NEE (by 23.21% at the grassland and 27.43% at the cropland) and sensible heat flux (with corresponding 9.90% and 11.98%), and underestimated the annual latent heat flux by 4.63% and 3.48%, respectively.

The possible reasons for the above inconsistence between model outputs and the direct measurements are uncertainties in long term observation on a basis of eddy covariance technique. These uncertainties include the limitation of physical instrumentation, effects of two or three dimensional air flow motion, methods of data processing, and underestimation of nighttime fluxes, etc. On the other hand, it also indicated the IBIS model needed improvements in several aspects especially its application in China's Semi-arid region, such as classification of vegetation types, verification of model variables suitable for the local ecosystems and so on. Meanwhile, it implied that great efforts are still needed for both experimental and model researches in the

future.

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